

ADSORPTION HEAT PUMP DEVELOPMENT AT JPL

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BACKGROUND)

In simple sorption refrigeration systems, low pressure gases are physically adsorbed onto or chemically absorbed into various solids, typically at near ambient temperatures or above (Figure 1). When heated an additional 100-300°C, the gases are desorbed, i.e., vented, at substantially higher pressures. When the high pressure gas is precooled and expanded through an orifice, known as a Joule-Thomson (J-T) valve, the gas becomes partially liquefied and provides net cooling. It then boils the liquid, and the returning low pressure gas is eventually reabsorbed by the sorbent, thus completing the cycle. The entire refrigeration system has essentially no wear-related moving parts, other than very long life, self-operating, room temperature check valves. Thus life expectancy is many years, possibly decades, and there is essentially no vibration.

Since 1979, the Jet Propulsion Laboratory (JPL) has tested numerous hydrogen, oxygen, nitrogen, and krypton cryogenic sorption refrigeration systems^(1,2) for cooling space-based infrared imaging systems. More recently, JPL has been developing a quick cooldown 10 K (-263°C) hydrogen sorption refrigeration system for the cooling of infrared sensors for the Strategic Defense Initiative Organization (SDIO) "Star Wars" missile tracking program. A proof-of-principle experiment was successfully conducted at JPL in 1991,⁽³⁾ and a JPL Space Shuttle flight experiment is planned for 1994.

For ground applications, the simple sketch of Figure 1 has been found to be too inefficient to compete with alternate heat pump technologies. To conserve energy, a number of heat regeneration techniques have been attempted, whereby the waste heat from one sorbent bed is used to heat another sorbent bed. Shelton⁴ and Tchernev⁵ have devised a simple double-bed system, in which a hot sorbent bed that is being cooled will pass its heat to a coolant fluid which then passes through a heater (to make up for regeneration thermal losses) and then on to another sorbent bed. A number of alternate techniques using four, six, or more beds have also been proposed,^{6,7}

Extensive studies have been performed at JPL, which show that a four bed approach is much more efficient than two beds, but there is not a significant advantage in using more than four beds.^{8,9} In particular, a patented four bed approach (Figure 2) will use a fluid (water or oil) to transfer hot and cold thermal waves.⁽¹⁰⁾ In addition, it has been discovered that significant performance improvement can be attained if the coolest sorbent bed is cooled further at the end of each quarter cycle

without regenerating the fluid through the other three sorbent beds. The results of the multiple bed analyses are shown Table 1.

In order to confirm the analytical tools, a single compact sorbent bed was fabricated and tested in both heating and cooling modes. The sorbent bed (Figure 3) consisted of activated carbon with a binder that was molded into a finned aluminum tube extrusion (patent pending⁽¹⁾). Pressurized water was selected as the heating and cooling means. A hollow ullage volume in the center of the water stream allowed enhanced fluid heat transfer coefficients. The transient test results showed very good correlation to analytical predictions⁽⁹⁾. Of the three refrigerants that were tested (R22, R134a, and ammonia), ammonia was clearly far superior and yielded 1038 BTU/hr (304 watts) cooling for only a 0.51 Kg carbon bed (Table 2.).

Coefficients of performance have been estimated for various standard heating and cooling conditions, and these are shown in Table 3. Modifications #1 and #2 are JPL/Caltech proprietary modifications that can greatly increase COP efficiencies.

APPLICATION/BENEFITS

The applications for the regenerative adsorption heat pump are air conditioning, heating, and refrigeration. The overall advantages of the advanced regenerative sorption heat pump over existing vapor heat pumps are

- Use of non-ozone depleting refrigerants
- Ability to use much lower greenhouse-effect fluids
- Long-life, reliable, solid-state compressors with no wear-related moving parts other than low frequency valves
- Use of any refrigerant with absolutely no lubrication requirements
- Noiseless and vibration-free compressor operation
- Inexpensive fabrication techniques and materials with no close tolerances or elaborate equipment required
- Use of long-life, reversible physical reactants, as opposed to corrosion-prone and potentially life-limiting chemical reactants
- Use of low pressure, single expansion, easily scalable systems, unlike complicated, high pressure, multi-stage liquid chemisorption systems that are corrosion-prone and cannot be scaled for small, home applications

- Greatly reduced winter and summer total fuel costs
- The condenser and compressor heat rejection systems can double as a domestic water heater to provide essentially free hot water while actually improving overall heat pump performance
- Significant net reduction in effluent pollution
- Reduction of U.S. dependence on foreign oil
- Reduction in electrical utilities peak load requirements of summer air conditioning

TECHNICAL ISSUES/ECONOMICS

The most pressing technical issue at present is the confirmation of predicted CoPs, and confirmation of long lifetimes. Lifetimes of other sorbent beds at JPL have exceeded 32,000 continuous hours without any degradation in performance. These beds, however, are of a different configuration and do not have heat transfer enhancement fins, and thus accelerated lifetimes should be performed for carbon/fin configurations similar to that shown in Figure 3.

Another technical issue to be addressed is the selection of water or a heat transfer oil as the coolant fluid. Water provides much better heat transfer, but it must be pressurized to at least 225 psi (1.5 Mpa). Dowtherm or Therminol heat transfer oils can operate at low pressure, but they are toxic and potentially flammable.

A possible coolant flow schematic is shown in Figure 4 with four sorbent beds. For this system, it is necessary to obtain long-life, low cost, multi-port valves to redirect the heat transfer fluid for each quarter cycle. Another economic issue that must be addressed are trade studies that optimized system cost by comparing a four-burner system with that of a single burner system using either flow diversions or heat exchangers for heating each of the four beds.

Fabrication costs for actual mass production are anticipated to be low, since the compressors have no moving parts, no close tolerances, and can be made from inexpensive carbon and aluminum heat transfer devices.

TECHNOLOGY OUTLOOK

JPL is a NASA field facility that is operated by the California Institute of Technology (Caltech). As such, JPL is non-profit and is not permitted to compete with private industry. JPL is, however, presently engaged in transferring the technology to private industry. A coalition team consisting of JPL, The Gas

Company of Southern California, and Aerojet is presently making plans for a three-ton air conditioning heat pump prototype that will be fabricated and tested within two years.

initial market penetration is anticipated to be for residential air conditioning/heat pump applications, with later applications of multi-family dwellings and possibly large scale industrial building applications. Refrigeration, including, mobile refrigeration, is also under consideration for development.

ACKNOWLEDGEMENTS

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Table J. Heat Pump Analytical comparisons

Sorbent/ Sorbate	2 Canister Max COP _c	4 Canister Orig Bottoming	6 Canister Orig Bottoming	12 Canister Orig Bottoming	Ideal COP _c
C/NH ₃	0.71	-- 1.02	0.92 1.06	1.01 1.16	1.46
C/R134a	0.61	-- 0.80	0.69 0.83	0.75 0.92	1.27
C/H ₂ O	1.20	-- --	1.471 --	--	1.60

Table 2. Measured Cooling Capacities

Sorbate	Total Cooling Capacity (BTU/hr)
R22	386
R134a	337
NH ₃	1038

Assumptions:

- Cooling capacity is measured over a 6 minute period with a 3 minute heating cycle and a three minute cooling cycle,
- Condenser saturation temperature = 100°F (37.8°C).
- Evaporator saturation temperature = 40°F (4.4°C).
- Total carbon weight is 0.51 kg with finned aluminum tube weight of 1.16 kg.

Table 3. Coefficients of Performance for Standard Heating and Cooling Days

Outdoor Temp. (F)	Outdoor Temp. (C)	Heat Pump Mode	COP Standard	COP Mod. #1	COP Mod. #2	Supplied Air Temp. (F)	Supplied Air Temp. (C)
95	35.0	Cooling	1.0	1.3	1.7	55	15.6
82	27.8	Cooling	1.3	1.6	2.1	55	12.8
47	8.3	Heating	1.9	2.1	2.4	105	35.0
17	-8.3	Heating	1.5	1.6	1.8	105	32.2

Note: These values do not include parasitic losses (estimated at about 3%) or electric fan power (estimated at about 5%). COPs may increase with alternate sorbents.

FIGURE 1. BASIC SORPTION REFRIGERATION CONCEPT

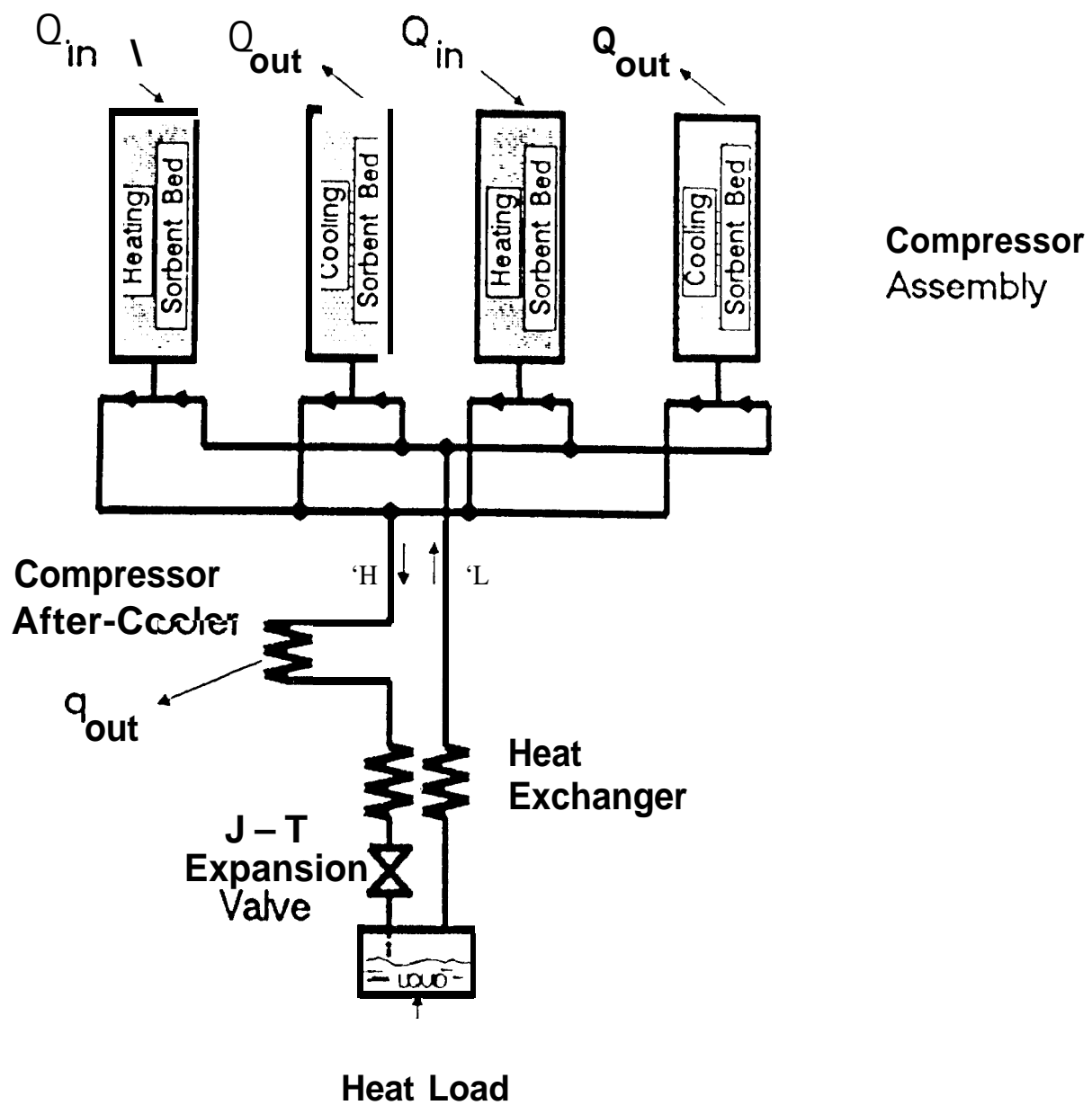
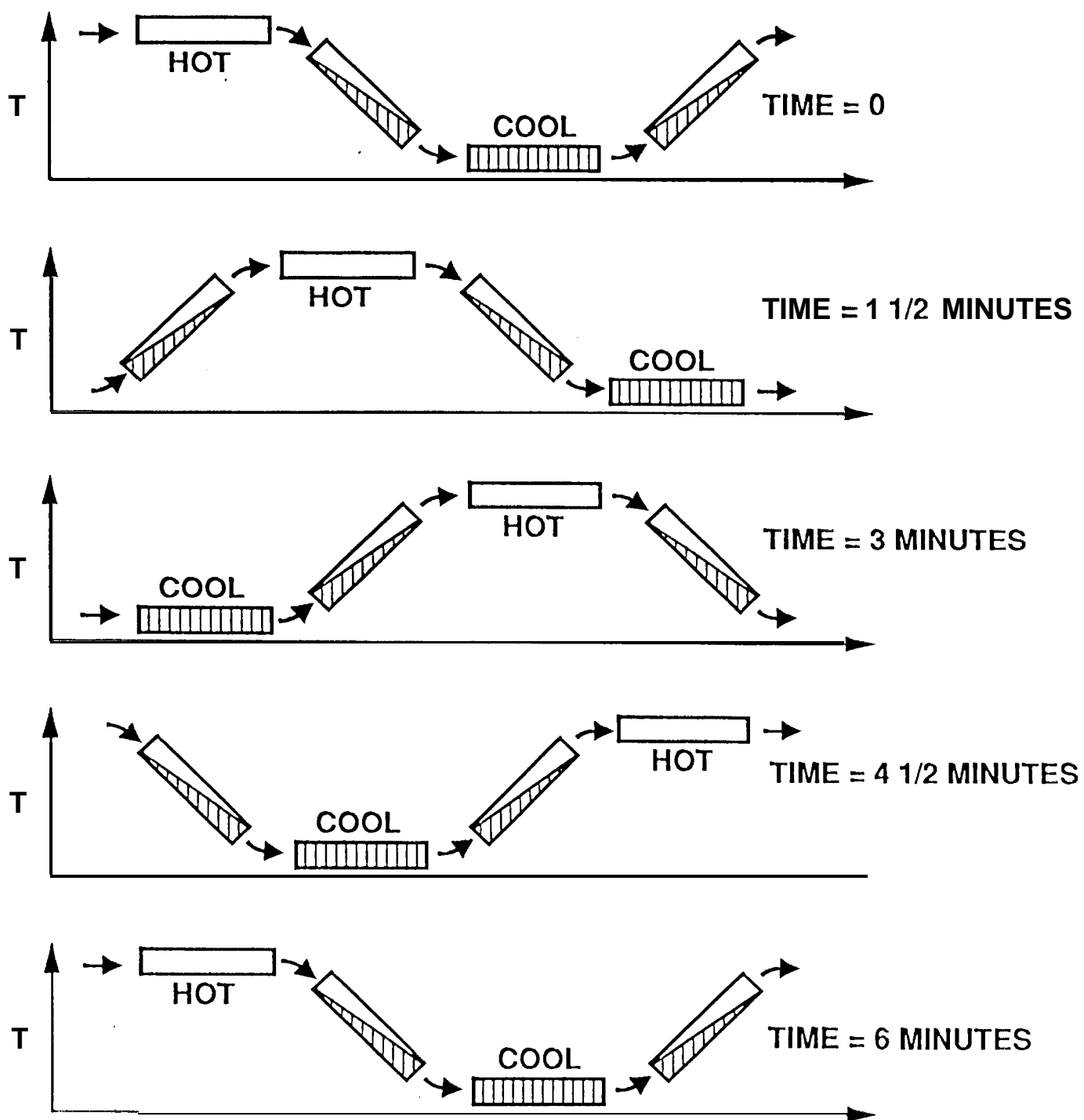


FIGURE 2. SORPTION COMPRESSOR REGENERATIVE THERMAL "WAVE"



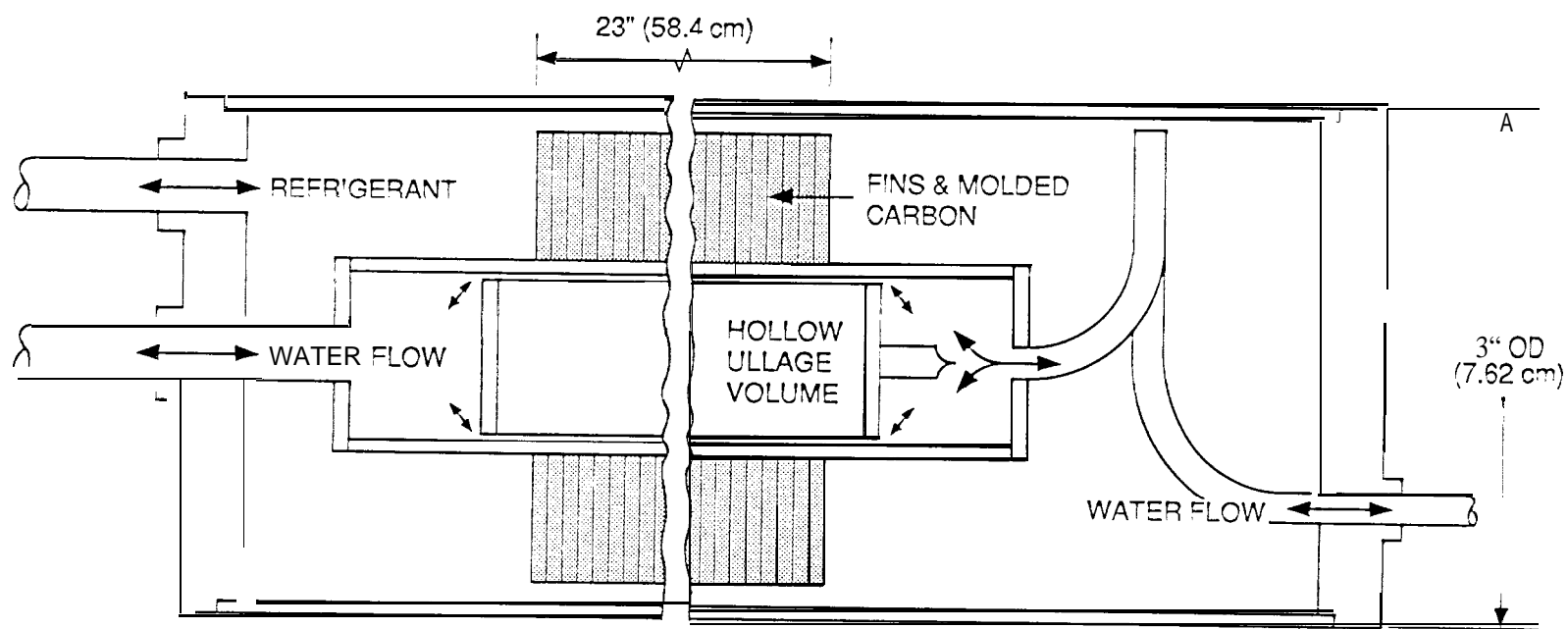
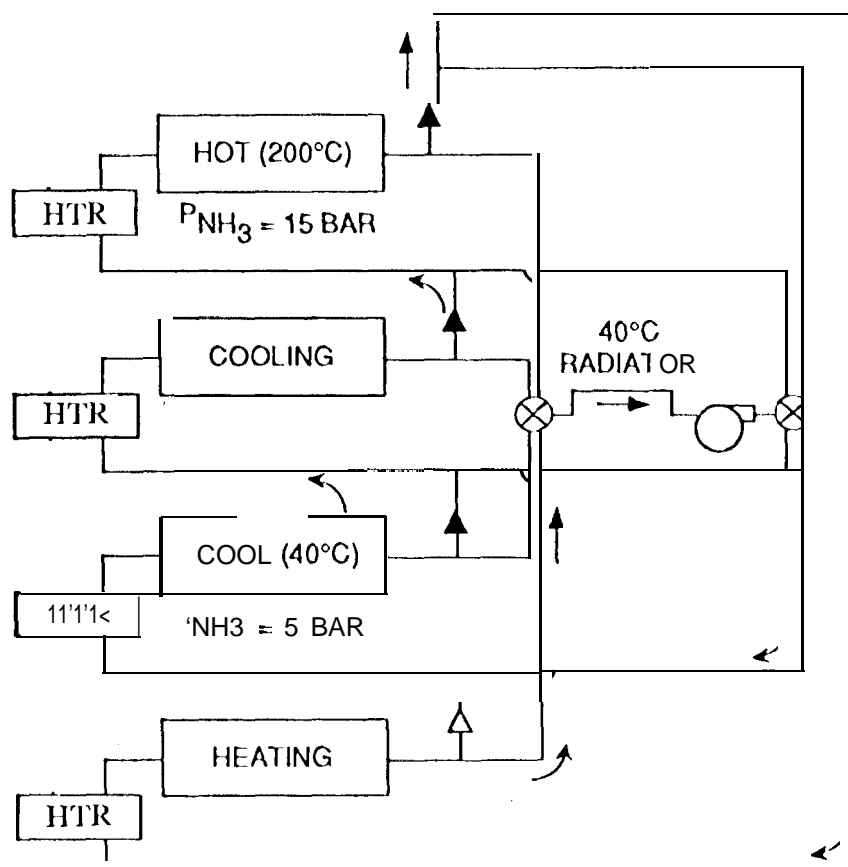


FIGURE 3. SORPTION COMPRESSOR ASSEMBLY CROSS-SECTION

FIGURE 4. COOLANT CIRCUIT DIAGRAM FOR SORBENT BEDS



Double?

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